

CONTEXT SPECIFICITY OF OPERANT DISCRIMINATIVE
PERFORMANCE IN PIGEONS: II. NECESSARY AND
SUFFICIENT CONDITIONS

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Six experiments were performed to explore the necessary and sufficient conditions for producing context specificity of discriminative operant performance in pigeons. In Experiment 1, pigeons learned a successive discrimination (red S+/blue S-) in two chambers that had a particular odor present and between which they were frequently switched. The birds subsequently learned the reversal (blue S+/red S-) in one of these chambers with a different odor present. When switched to the alternative chamber, although the odor and the reinforcement contingency were still appropriate to the reversal, performance appropriate to the original discrimination recurred in subjects for which the houselights were on during training and testing but not for those for which the houselights were off. This indicated the importance of visual contextual cues in producing context specificity. Experiment 2 showed that the frequent switching between boxes in initial training was of no consequence, presumably because the apparatus cues were highly salient to the subjects. Experiment 3 showed significantly less context specificity when odor cues were omitted. Experiment 4 showed that simply using a different reinforced stimulus in each phase of training was ineffective in producing context specificity. Experiment 5 showed that the generalization test procedure used in Experiment 4 was sensitive to context specificity when discrimination-reversal training was used with different odors in the two training phases. Experiment 6 replicated the results of Experiment 4, but then showed that when different odors accompanied the two training phases, context specificity was obtained with the single-stimulus paradigm. Thus in both single-stimulus and discrimination-reversal paradigms, redundant odor cues potentiated learning about apparatus cues.

Key words: context specificity, discrimination learning, reversal learning, odor cues, potentiation, contextual stimuli, recency effect, generalization testing, key peck, pigeons

In a recent paper, we reported an unexpected and unintended instance of conditional stimulus control by the contexts in which pigeons had learned a successive key-color discrimination and its reversal (Thomas & Empe-
docles, 1991). The experiment was originally intended to investigate odors as potential "retrieval cues" in pigeons' memory (i.e., as implicit conditional stimuli). The birds first learned to peck a red keylight (S+, reinforced) and not a blue one (S-, extinguished) in the presence of either a eucalyptus oil or isoamyl acetate odor. They were repeatedly switched between two chambers with the same odor to habituate any reaction to the switching that would be required for eventual testing for conditional control by the odors. Next, the birds learned the reversal (blue S+/red S-) in the presence of the alternative odor in one of these

chambers. When the birds were then switched to the alternative chamber for additional training, although the odor and the reinforcement contingency were still appropriate to the reversal problem, behavior appropriate to the original training condition recurred (i.e., the birds pecked more at red than at blue).

Two interpretations of this unexpected finding were considered. One was that the handling and switching of birds between chambers had come to serve as a cue signaling the original red S+/blue S- contingency. This hypothesis was rejected based on the results of two tests: (a) Switching the birds back to the chambers in which they had learned the reversal immediately reinstated excellent reversal performance, and (b) a pseudoswitch, in which the birds were removed from but then returned to the same chambers, had no effect on their performance.

The second interpretation was that features of the different operant chambers had gained conditional control over the birds' discriminative performance despite the fact that the chambers were designed to be as similar to each other as possible. Furthermore, the fre-

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quent switching of the birds between chambers in initial training was expected to invalidate any cue value that detectable differences between the chambers might have had. In addition, the presence of highly salient odor cues during original discrimination and subsequent reversal training had been expected to overshadow any control that apparatus features might otherwise have acquired, yet they clearly did not. We assumed that the odors that we used would be highly salient, based on the results of an earlier study (Thomas & Empeocles, 1992). In that study, we showed that a switch from one of these odors, which had been present during training, to the alternative odor substantially disrupted ongoing operant behavior.

The unexpected finding of context specificity (conditional control) raised many intriguing questions that fell into two general categories. First, what were the particular attributes of the different operant chambers that had acquired control over the subjects' discriminative performance? Second, what aspects of our training procedures were necessary and/or sufficient to produce our obtained result? Experiments relevant to both of these questions will be reported in this paper.

EXPERIMENT 1

Visual inspection of the different chambers revealed some subtle differences in the location of screw holes, the type of screw heads, the pattern of wear in the aluminum wall of the intelligence panel next to the response key, and so forth. Experiment 1 was designed to test the hypothesis that visual cues played a role in the context-specificity effect. For this purpose, the original experiment was replicated except that the houselights in the chambers were not used. Although the illuminated key projected some light into the chamber during trials, subtle visual differences between the chambers should be much less conspicuous. To the extent that they play a role in context specificity, the effect should be eliminated or decreased in magnitude when the houselights are not used. Another group of subjects was trained and tested as in the original experiment. The purpose of this group was to provide a replication of the original finding and also to provide a suitable baseline for comparison with all the other training and test procedures used

in the various experiments reported in this paper. For practical purposes, in the present experiments training sessions were 20 min in duration, rather than 30 min as in the original experiment. This made it inappropriate to use the results of the original experiment to assess differences in the magnitude of the context-specificity effect.

METHOD

Subjects

The subjects were 16 experimentally naive common pigeons obtained from a local supplier and maintained at 80% of their ad-lib weights. They were housed in individual cages in a colony room with a 12:12 hr light/dark cycle. Light onset was at 6:00 a.m., and sessions were conducted 7 days per week.

Apparatus

The apparatus consisted of a set of four standard operant conditioning chambers (described by Thomas, McKelvie, Ranney, & Moye, 1981). The exhaust fan in each box was disconnected so as not to dissipate the odors placed in the different chambers in some of the experiments reported here. The stimuli on the response key were produced by IEE projectors (Series 0010) with No. 1864 lamps operated at 24 V. The houselight was a No. 1815 lamp operated at 24 V. Kodak Wratten filters Nos. 75 and 72B produced nominal peak transmitted wavelengths of 490 nm (blue) and 606 nm (red), respectively. A white-noise generator provided masking noise. Reinforcement was 3 s of access to a food hopper filled with mixed grain. Recording and control were accomplished with the use of a Commodore Pet Professional® computer (Model 2001) with a locally designed and constructed interface.

Procedure

The 16 birds were divided at random into two groups ($n = 8$) that differed only in whether the houselights in the operant chambers were illuminated during the 55-s stimulus-on periods (Group HL) or were off throughout the experiment (Group $\overline{\text{HL}}$). On Day 1 all birds were magazine trained, the key peck was shaped via reinforcement of successive approximations while the key was illuminated by a 606-nm (red) light, and each bird was allowed to earn approximately 60 reinforcers on a variable-interval (VI) schedule with a

gradually increasing mean interreinforcement interval. On Day 2 the subjects were given single-stimulus training with the 606-nm keylight until 60 reinforcers were earned on a VI 30-s schedule. Starting on Day 3, the birds received the first of seven 20-min sessions of (multiple schedule) successive discrimination training in which 606 nm (red) was the S+ (signaling VI 30-s reinforcement) and 490 nm (blue) was the S- (signaling extinction). Component stimulus presentations ("trials") were 55 s long and were separated by 5-s time-outs during which both the keylight and the houselight (in Group HL) were turned off and reinforcement was unavailable. The S+ and S- presentations were arranged in an unsystematic order, except that each session consisted of 20 trials during which the S+ and the S- were each presented 10 times and each block of five trials contained no more than three presentations of either stimulus.

In two of the four chambers, 0.5 cc of eucalyptus oil was added to paper toweling beneath the grid floor of the operant chamber on each day of the experiment. Each of the other two chambers contained 0.5 cc of isoamyl acetate. Eight birds were initially trained in the presence of each odor. Starting on Day 3 and continuing throughout the initial phase of discrimination training, at 5-min intervals the session was interrupted, each bird was switched to the alternative chamber containing the same odor, and the session was resumed.

After the seventh session of Phase 1 discrimination training (i.e., red S+/blue S-), reversal training began in a chamber with the alternative odor present. The odors in the four chambers were switched so that the subjects could continue to be trained in the same chambers as previously experienced. Prior to the introduction of the new odor, the chambers were thoroughly wiped down with water and odor-free soap and were aired out overnight with an odor absorbent (NonScents®). Because responding to the blue keylight was so thoroughly extinguished in Phase 1, one session was dedicated to hand shaping pecking at this stimulus before progressing to reversal training. On the next day, reversal training began using the same parameters as used in Phase 1, except that now blue was the S+ and red was the S-. This training continued for five sessions (Sessions 11 through 15). The birds were not switched between chambers un-

til the fourth session of reversal training (Session 14). They were switched once during this session, after 10 min of training had been completed. During the final session (Session 15), the birds were started in the box in which they had finished the previous session; they were switched once after 10 min, followed by a pseudoswitch 10 min later. As during Phase 1 discrimination training, the switch was always to a chamber containing the same odor.

RESULTS AND DISCUSSION

Because Group HL provides a replication of the original experiment by Thomas and Empedocles (1991), the data from these subjects will be considered first. All subjects mastered the red S+/blue S- discrimination problem within a few sessions, and by the seventh (last) session of Phase 1 training, the subjects averaged more than 96% of total responses to the S+ (red) stimulus. Initially, performance was disrupted when subjects were switched between chambers, but the disruptions grew shorter and, in most cases, disappeared altogether. Thus, the discrimination ratios obtained on each block of five trials (between switches), corrected for the different number of S+ and S- trials, remained constant throughout the session.

In the top row of Table 1 are presented the discrimination ratios (i.e., percentage of responses to S+) obtained from each subject in Group HL during the last session of red S+/blue S- training (Session 9). Most subjects were performing extremely well by this time. The next row shows the discrimination ratios calculated over the last full session of reversal (blue S+/red S-) training (Session 14). All subjects had reversed their preference between red and blue by this time. The next row in the table presents the discrimination ratios calculated over the first 10 min of the next training session (Test Day 1) while the birds were still in the box in which all reversal training had been carried out. The birds continued to perform well on the reversal problem. The next row is the critical one. It shows the result of the switch to the alternative chamber. For every bird, performance appropriate to the original red S+/blue S- discrimination contingency recurred, despite the fact that the odor and the reinforcement contingency were the ones appropriate to the reversal. Thus the results of the original Thomas and Empedocles

Table 1
Discrimination ratios during various phases of training and testing in Experiment 1 (Group HL).

	Bird 1	Bird 2	Bird 3	Bird 4	Bird 5	Bird 6	Bird 7	Bird 8
	Boxes 1 and 2 (E)	Boxes 1 and 2 (E)	Boxes 3 and 4 (I)	Boxes 3 and 4 (I)	Boxes 1 and 2 (E)	Boxes 1 and 2 (E)	Boxes 3 and 4 (I)	Boxes 3 and 4 (I)
Last day R+ B-	84.0	99.9	99.2	93.9	97.9	100	100	94.8
	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)
Last full day B+ R-	86.3	95.8	86.2	77.9	74.0	90.4	99.8	86.9
1st 10 min Test Day 1	83.7	73.4	76.0	91.1	71.2	88.2	100	71.3
	Box 2 (I)	Box 1 (I)	Box 4 (E)	Box 3 (E)	Box 2 (I)	Box 1 (I)	Box 4 (E)	Box 3 (E)
2nd 10 min Test Day 1	43.0 (-40.7)	30.8 (-42.6)	40.5 (-35.5)	47.5 (-43.6)	38.4 (-32.6)	20.3 (-67.9)	47.6 (-52.4)	40.4 (-30.9)
1st 10 min Test Day 2	81.2	67.6	84.5	60.0	60.8	75.2	85.5	61.3
	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)
2nd 10 min Test Day 2	90.8 (+9.6)	77.1 (+9.5)	65.8 (-18.7)	99.4 (+39.4)	63.2 (+2.4)	90.7 (+15.5)	93.9 (+8.4)	85.8 (+24.5)
Pseudoswitch	98.3	72.9	72.9	100	69.3	89.5	96.8	83.8
3rd 10 min Test Day 2	(+7.5)	(-4.2)	(+7.1)	(+0.6)	(+6.1)	(-1.2)	(+2.9)	(-2.0)

Note. E and I refer to eucalyptus oil and isoamyl acetate, respectively. The numbers in parentheses refer to the change in discrimination ratio due to the preceding manipulation.

(1991) study were replicated, despite small procedural differences (in the duration and number of training sessions in each phase). The change in discrimination ratios that occurred after the switch between chambers could have resulted from a reduction in responding to S+, from an increase in responding to S-, or from both of these effects. During the first 10 min of the session, the subjects emitted an average of 83.6 responses per trial to S+ and 22.6 responses per trial to S-. During the second 10 min, they responded an average of 51.6 times per trial to S+ and 77.1 times per trial to S-. All 8 subjects showed increases in responding to S-, and 7 of the 8 showed reductions in responding to S+. Both the change in S+ responding and in S- responding were statistically significant, $t(7) = 2.95, p < .05$ and $t(7) = 8.25, p < .01$, respectively. The change in S- responding was much more dramatic, however, indicating that the reversal in discrimination performance was attributable primarily to the enhancement of responding in the presence of S-, the stimulus that had signaled reinforcement availability when the subjects were previously in that chamber. This pattern of changes in responding replicates that seen in the original study (Thomas & Empe-
docles, 1991).

There are several possible measures of the magnitude of the context-specificity effect. The simplest of these is the discrimination ratio obtained in the 10 min subsequent to returning the birds to the chamber in which they had learned the original (red S+/blue S-) discrimination. The mean discrimination ratio for Group HL was 38.6%, which is significantly less than 50%, $t(7) = 3.55, p < .01$, and indicates that the preference for the red stimulus established during original training was re-instated. An alternative measure of the magnitude of the context-specificity effect is the amount of change in the discrimination ratio from its preswitch to its postswitch value (i.e., from the first 10 min to the second 10 min of the first day of testing). On average, in Group HL the discrimination ratios were reduced by 43.2%. Table 1 also shows the results of further testing on the next day. During the first 10 min of Test Day 2, all birds showed improvement in their reversal performance relative to what it had been in that chamber during the preceding session. Nevertheless, when the birds were switched back to the chambers in which reversal training had originally been carried out, their reversal performance typically improved dramatically. The amount of improve-

Table 2

Discrimination ratios during various phases of training and testing in Experiment 1 (Group HL).

	Bird 1	Bird 2	Bird 3	Bird 4	Bird 5	Bird 6	Bird 7	Bird 8
	Boxes 1 and 2 (E)	Boxes 1 and 2 (E)	Boxes 3 and 4 (I)	Boxes 3 and 4 (I)	Boxes 1 and 2 (E)	Boxes 1 and 2 (E)	Boxes 3 and 4 (I)	Boxes 3 and 4 (I)
Last day R+ B-	100	79.8	100	94.6	93.6	91.3	100	100
	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)
Last full day B+ R-	95.7	67.0	86.2	98.2	92.8	90.5	88.7	99.4
1st 10 min Test Day 1	98.5	74.7	92.9	89.4	98.4	92.5	98.1	100
	Box 2 (I)	Box 1 (I)	Box 4 (E)	Box 3 (E)	Box 2 (I)	Box 1 (I)	Box 4 (E)	Box 3 (E)
2nd 10 min Test Day 1	80.5 (-18.0)	62.5 (-12.2)	77.9 (-15.0)	46.7 (-42.7)	69.5 (-28.9)	76.5 (-16.0)	69.0 (-29.1)	92.8 (-7.2)
1st 10 min Test Day 2	98.2	77.8	86.3	90.8	78.9	92.5	96.0	100
	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)
2nd 10 min Test Day 2	99.1 (0.9)	78.9 (1.1)	98.2 (11.9)	97.0 (6.2)	99.2 (20.3)	86.3 (-6.2)	97.1 (1.1)	100 (0)
Pseudoswitch	99.5	91.0	98.5	100	100	87.5	97.9	100
3rd 10 min Test Day 2								

Note. E and I refer to eucalyptus oil and isoamyl acetate, respectively. The numbers in parentheses refer to the change in discrimination ratio due to the preceding manipulation.

ment in the obtained discrimination ratios is shown (in parentheses) on the next line.

The improvement in performance of the blue S+/red S- discrimination upon returning the birds to the box in which that discrimination had been learned is further evidence of context specificity. It indicates that the functional cue governing discriminative performance was the chamber in which training took place and not the experience of being handled within sessions. Because switching and the accompanying handling had taken place only during initial (red S+/blue S-) training, it had the potential to serve as a cue signaling the reinforcement contingency that had been in effect at that time. Had it done so, the switch between boxes during Test Day 2 would have resulted in a degrading rather than an enhancing of performance, as would the pseudoswitch that was subsequently carried out. Note that when the pseudoswitch was done, performance was unaffected (see the small and unsystematic changes in discrimination ratios presented in parentheses on the next line of Table 1).

Table 2 presents the results for Group HL in the same format as that in Table 1. The question is whether context specificity occurred in this group, despite the fact that visual cues were less conspicuous than for Group

HL. Clear evidence of context specificity was again found. When the birds were switched (on Test Day 1) to a box in which they had not experienced the reversal problem, all 8 birds showed some disruption of reversal performance. This disruption may be taken as evidence of context specificity, because the birds had been switched repeatedly back and forth between the two chambers during the initial phase of discrimination training with no measurable effect on their performance. As shown in Table 2, the reduction in the discrimination ratio was substantially lower than in Group HL, and in only one case (Bird 4) was performance appropriate to the original (red S+/blue S-) contingency reinstated. On the next day, when the birds were returned to the boxes in which reversal training had been initiated, their performance improved somewhat.

The results indicate that the degree of context specificity was lower in Group HL than it had been in Group HL. The group mean discrimination ratio during the second 10 min of Test Day 1 was 71.9%, which is significantly greater than 50%, $t(7) = 4.54$, $p < .01$. A direct comparison between the amount of context specificity obtained in the two groups can be accomplished by comparing the amount of reduction in the discrimination ratios when the

birds were switched between boxes on the critical (first) test day. This comparison is conservative because Group HL performed somewhat better on the reversal problem prior to the switch, with a mean discrimination ratio of 93.1% compared to 81.9% in Group HL in the first 10 min of the test session. Nevertheless, the mean reduction in discrimination ratio for Group HL, 21.1%, was statistically significantly less than the 43.2% for Group HL, $t(14) = 4.29$, $p < .01$.

The use of the first 10 min of the test session as a baseline for determining the effect of the switch between chambers has the advantage of temporal proximity, but it might be argued that the previous day's entire session would provide a more stable baseline. Furthermore, these baselines are more nearly identical for the two groups, with discrimination ratios of 87.2% in Group HL and 89.8% in Group HL. Using these baselines, the mean reduction in discrimination ratios was 48.5% for Group HL and 17.8% in Group HL, $t(14) = 6.54$, $p < .01$. Thus, the degrading of visual contextual cues substantially and significantly reduced the degree of context specificity obtained.

It is not appropriate to compare statistically the amount of improvement on the second test day when the birds were switched back to the boxes in which reversal training had been initiated. This measure is a useful addendum to the primary measure of decrement in performance on the preceding day, but it is not independent of it. The more poorly the subjects perform after the switch, the greater their opportunity to improve when switched back.

It is possible that context specificity is entirely dependent on visual cues, because light reflected from the illuminated key may have been sufficient for the subjects to detect some (but not all) distinguishing features of the different chambers. On the other hand, nonvisual contextual cues may have contributed to the context-specificity effect. We can conclude with certainty only that visual cues play an important role in the obtained effect.

EXPERIMENT 2

The frequent switching of the pigeons between two chambers in initial discrimination training in the original experiment was designed to invalidate apparatus cues, but it may have had the opposite effect (or none at all).

It is possible to suggest that the contrast between being switched back and forth between two chambers in Phase 1 and being trained in only one box in Phase 2 caused subjects to be more attentive to apparatus cues than they otherwise would have been.

It is well established that conditional discrimination training may be facilitated by providing subjects with frequent and repeated alternations of conditional cues (see Thomas, Cook, & Terrones, 1990; Thomas, Stengel, Sherman, & Woodford, 1987), and in the case of cues that are not very salient, such alternations may be essential. Experiment 2 was performed to test the role of frequent switches between chambers in the initial phase of training. In the original experiment the subjects received half of their Phase 1 training in each of two chambers and were switched between the two every 5 min. In the present experiment they experienced the entire initial phase of training in one box and reversal training in a different box.

METHOD

Subjects and Apparatus

The subjects were 8 experimentally naive pigeons maintained as in Experiment 1. The apparatus was the same as that used in Experiment 1.

Procedure

The procedure was the same as that used for Group HL of Experiment 1, with the exception that all seven sessions of Phase 1 red S+/blue S- training took place in a single chamber. To equate their handling experience with that in the original experiment, the birds received pseudoswitches every 5 min (i.e., they were removed from and then returned to the same boxes). Reversal training and subsequent testing were carried out as for Group HL in Experiment 1.

RESULTS AND DISCUSSION

A very strong context-specificity effect is evident in Table 3. Indeed, on Test Day 1 all 8 subjects performed appropriately to the original red S+/blue S- contingency when switched to the box in which that discrimination had been acquired. Furthermore, the degree of specificity was as great as in Group HL of Experiment 1. On average, the switch

Table 3

Discrimination ratios during various phases of training and testing in Experiment 2 (one switch).

	Bird 1	Bird 2	Bird 3	Bird 4	Bird 5	Bird 6	Bird 7	Bird 8
	Box 1 (E)	Box 2 (E)	Box 3 (I)	Box 4 (I)	Box 1 (E)	Box 2 (E)	Box 3 (I)	Box 4 (I)
Last day R+ B-	99.5	96.1	84.0	87.1	100	97.3	99.1	99.8
	Box 2 (I)	Box 1 (I)	Box 4 (E)	Box 3 (E)	Box 2 (I)	Box 1 (I)	Box 4 (E)	Box 3 (E)
Last full day B+ R-	81.2	76.3	65.3	65.5	68.6	98.3	72.2	99.6
1st 10 min Test Day 1	88.5	77.8	73.6	76.2	88.8	98.7	83.5	98.3
	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)	Box 1 (I)	Box 2 (I)	Box 3 (E)	Box 4 (E)
2nd 10 min Test Day 1	41.3	18.5	37.7	38.8	26.9	39.0	38.6	47.6
	(-47.2)	(-59.3)	(-35.9)	(-31.6)	(-61.9)	(-59.7)	(-44.9)	(-50.7)
1st 10 min Test Day 2	70.0	53.1	57.4	55.4	47.5	56.5	57.4	66.5
	Box 2 (I)	Box 1 (I)	Box 4 (E)	Box 3 (E)	Box 2 (I)	Box 1 (I)	Box 4 (E)	Box 3 (E)
2nd 10 min Test Day 2	93.3	69.0	84.2	95.9	47.7	99.7	92.5	100
	(+23.3)	(+15.9)	(+26.8)	(+40.5)	(+0.2)	(+43.2)	(+35.1)	(+33.5)
Pseudoswitch	95.6	68.2	73.3	90.4	66.3	98.3	99.5	98.4
3rd 10 min Test Day 2	(+2.3)	(-0.8)	(-10.9)	(-5.5)	(+18.6)	(-1.4)	(+7.0)	(-1.6)

Note. E and I refer to eucalyptus oil and isoamyl acetate, respectively. The numbers in parentheses refer to the change in discrimination ratio due to the preceding manipulation.

produced a reduction of 48.9% in the discrimination ratios, not significantly different from the 43.2% observed in the control group ($t < 1$). Thus, the frequent switches between the two chambers for Group HL played no role in the subjects' learning to distinguish between the two chambers and subsequently associating chamber cues with the contingencies experienced in their presence.

This result is consistent with that obtained by Thomas and Goldberg (1985) in a single-reversal study that used houselight and tone versus houselight-off and white noise as context cues. That study compared single-reversal, daily-reversal, and minute-by-minute reversal training, in which the context was alternated only once, from each day to the next, or from each minute to the next, respectively. In each group, generalization gradients peaked at the appropriate color (i.e., the one that had been S+ in that context), but the degree of conditional control was actually lowest under the minute-by-minute condition. Presumably, the contexts were so salient that frequent comparisons between them were unnecessary for them to acquire control over discriminative responding. The same seems to be true of the box cues used in the present experiments. In our next experiment, we questioned the role of the odors used in the original experiment.

EXPERIMENT 3

The odor cues that were present during original discrimination and reversal training were expected to overshadow any apparatus cues, but the magnitude of the observed context specificity was so great as to suggest that the odors may have had the opposite effect, potentiating learning about apparatus cues. To test this hypothesis, the original experiment was replicated, except that no explicit odor cues were used in the operant chambers at any time.

METHOD

Subjects and Apparatus

The subjects were 8 experimentally naive pigeons maintained as in Experiment 1. The apparatus was the same as that used in Experiment 1.

Procedure

The procedure was the same as that used for Group HL of Experiment 1, with the exception that no extra odor was present in the operant chambers at any time during the experiment.

RESULTS AND DISCUSSION

Table 4 presents the results of this experiment. It is clear that switching the birds to the

Table 4

Discrimination ratios during various phases of training and testing in Experiment 3 (no odor).

	Bird 1	Bird 2	Bird 3	Bird 4	Bird 5	Bird 6	Bird 7	Bird 8
	Boxes 1 and 2	Boxes 1 and 2	Boxes 3 and 4	Boxes 3 and 4	Boxes 1 and 2	Boxes 1 and 2	Boxes 3 and 4	Boxes 3 and 4
Last day R+ B-	96.4	99.7	91.1	97.0	98.7	100	99.9	98.8
Last full day B+ R-	77.5	45.1	89.1	88.2	72.4	75.8	93.1	70.5
1st 10 min Test Day 1	81.0	65.7	91.1	94.7	96.9	77.9	91.4	74.3
	Box 2	Box 1	Box 4	Box 3	Box 2	Box 1	Box 4	Box 3
2nd 10 min Test Day 1	57.9	53.6	65.9	52.5	54.3	59.1	51.9	49.3
	(-23.1)	(-12.1)	(-25.2)	(-42.2)	(-42.6)	(-18.8)	(-39.5)	(-25.0)
1st 10 min Test Day 2	79.4	73.4	61.2	89.4	61.0	75.9	69.9	63.6
	Box 1	Box 2	Box 3	Box 4	Box 1	Box 2	Box 3	Box 4
2nd 10 min Test Day 2	97.1	70.4	100	100	77.0	97.2	97.8	86.3
	(+17.7)	(-3.0)	(+38.8)	(+10.6)	(+16.0)	(+21.3)	(+27.9)	(+22.7)
Pseudoswitch	93.5	89.6	93.9	100	94.6	100	98.8	98.2
3rd 10 min Test Day 2	(-3.6)	(+19.2)	(-6.1)	(+0.0)	(+17.6)	(+2.8)	(+1.0)	(+11.9)

Note. The numbers in parentheses refer to the change in discrimination ratio due to the preceding manipulation.

chamber in which they had learned only the red S+/blue S- task severely disrupted reversal performance, reducing it to a chance level. Thus, although the cues from that chamber were insufficient to reinstate Phase 1 performance, they were sufficient to prevent the transfer of reversal performance. The reduction in the discrimination ratio that resulted from the switch between boxes averaged 28.6%, which is significantly less than the 43.2% observed in Group HL from Experiment 1, $t(14) = 2.53$, $p < .05$. This difference suggests that the use of odor cues in the Group HL potentiated learning about other contextual cues rather than overshadowing such learning.

Perhaps the use of a reversal paradigm is a necessary and/or sufficient condition for producing the context-specificity effect. Recall Kamin's (1969) proposal that it is "surprise" or the violation of an expectancy that is essential for learning. What could be more surprising than the switch from responses to red and not blue being reinforced to being reinforced for responding to blue and not red?

EXPERIMENT 4

To test for the role of reversal training, we performed an experiment in which subjects received single-stimulus training to peck red (in Phase 1) and to peck blue (in Phase 2). There was no hue S- in either phase of training. To accommodate this difference in training procedure, there also had to be a change

in test procedure. The critical question was whether the subjects would respond more to blue (and less to red) in that box in which they had only learned to peck blue. Because the subjects had never seen both red and blue stimuli within a single session, it was not obvious what the appropriate test procedure should be. Given the likelihood that reinforcing responding to both red and blue in both boxes would quickly abolish stimulus control by the colors and/or the boxes, it was decided to test for context specificity (i.e., conditional control) in our traditional way (i.e., generalization testing in extinction with the two contexts [boxes] alternating in blocks of test trials; see Thomas *et al.*, 1981).

METHOD

Subjects and Apparatus

The subjects were 8 experimentally naive pigeons maintained as in Experiment 1. The apparatus was the same as that used in Experiment 1. However, in addition to Kodak Wratten filters Nos. 75 and 72B, which produced nominal peak transmitted wavelengths of 490 nm (blue) and 606 nm (red), respectively, three other filters were used. They were No. 74 (538 nm, green), No. 99 (555 nm, yellowish green), and No. 73 (578 nm, yellow).

Procedure

No extra odor was present in the chambers at any time during the experiment. In Phase 1, which consisted of seven 20-min sessions,

subjects received VI 30-s reinforcement for responding to red, which was the only color presented during the 55-s trials. As in the prior experiments, trials were separated by 5-s time-out periods. Blue was the only color present during trials in Phase 2, which lasted for 3.5 20-min sessions. As in the prior experiments (except Experiment 2), the birds were switched between boxes every 5 min in Phase 1 but were trained in only one of those boxes in Phase 2. As in the other experiments, testing was initiated at the completion of 10 min of training on the fourth session of Phase 2.

During testing, five different wavelengths, 490 nm (the Phase 2 training stimulus), 538 nm, 555 nm, 576 nm, and 606 nm (the Phase 1 training stimulus), were randomized within blocks. Each subject experienced two such blocks in one chamber before being switched to the other box for two test blocks, then back, and finally back again so that four test blocks were experienced in each box. The test was carried out in extinction. Stimulus-on periods (trials) were 55 s long and were separated by 5-s blackouts, as during training. Testing was counterbalanced, such that half of the subjects began testing in the box in which they had received Phase 2 training and half started in the alternative box.

RESULTS AND DISCUSSION

In past research in this laboratory using a single-reversal design, it has been shown that subjects tend to respond in accordance with the reversal contingency (i.e., they show recency; see Thomas et al., 1981; Thomas, Moye, & Kimose, 1984). Only when testing in the presence of contextual cues that had accompanied initial training and not reversal training may this recency effect be overcome and responding appropriate to the original training contingency exhibited. This finding is critical in order to demonstrate the function of the original training context as a "retrieval" cue. Appropriate responding in the presence of the context that had accompanied reversal training is not as informative, because such responding might be expected on the basis of recency alone.

The present experiment differs from past ones in our laboratory in that subjects were exposed to single-stimulus training rather than discrimination training in both phases of training; thus, they were never trained not to respond to the red Phase 1 training stimulus.

Furthermore, in the present experiment the subjects received less than half as much training to respond to blue than they had received to respond to red. This might reduce the magnitude of the recency effect or eliminate it altogether, making responding during generalization testing more sensitive to context effects, if there are any.

Figure 1 presents the individual and the group average generalization gradients of subjects calculated separately for the two chambers, the one used in both phases of training and the one used only in Phase 1. The results are very consistent across subjects. Even when tested in the chamber in which they had learned to peck blue in Phase 2, the subjects showed no recency effect. Regardless of the chamber in which they were tested, the birds responded substantially to both red and blue; on average they responded slightly more to red than to blue, with much less responding to intermediate test values. Summed over all five test stimuli, the subjects averaged 641.3 test responses in the chamber used in both phases of training and 436.8 responses in the chamber used only in Phase 1. This difference is of borderline statistical significance, $t(7) = 2.31$, $p < .06$, but it was observed with 7 of the 8 subjects. It is not surprising that the subjects responded less in the chamber in which they had received less training and in which they had not been trained during the immediately preceding three sessions. The obtained difference is important because it suggests that the subjects discriminated between the different chambers; this is a precondition for the demonstration of context specificity, but it does not guarantee it. The critical finding is that on average the subjects responded as much to blue as to red in a chamber in which they had never experienced blue prior to testing. Indeed, responding to blue relative to responding to red was very similar in the two chambers. It is this finding that indicates the absence of context specificity and suggests that reversal training may be necessary for producing the specificity effect.

EXPERIMENT 5

Before drawing a definitive conclusion about the difference in training paradigms, the difference in test procedures between Experiment 4 and the preceding experiments needs to be

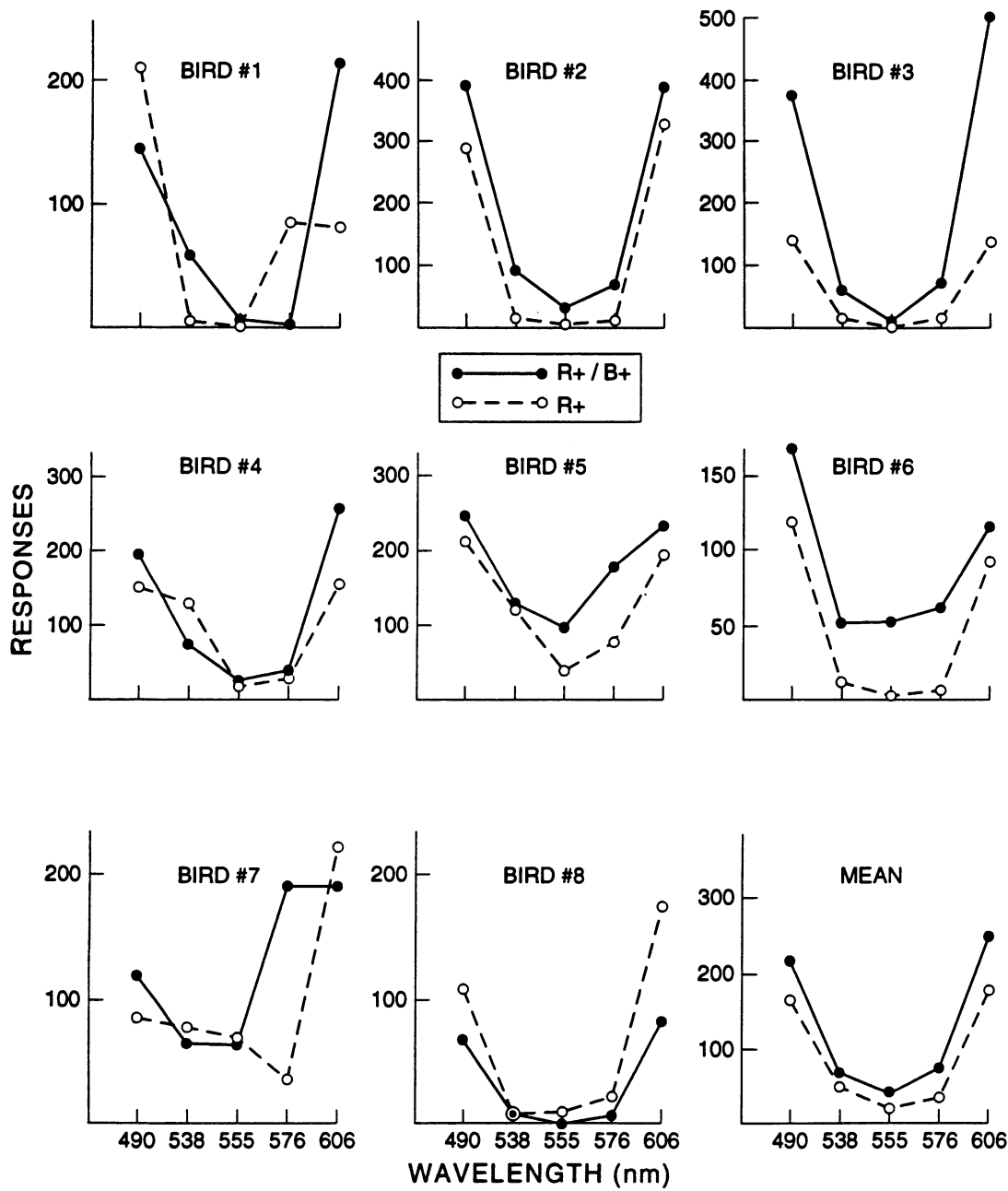


Fig. 1. Individual and group average wavelength generalization gradients obtained in two chambers, the one used in both Phase 1 and Phase 2 of training (R+/B+) and the one used only in Phase 1 (R+). Note that each subject was trained in two boxes during Phase 1 and in only one of those two boxes in Phase 2. The training stimuli used were 606 nm (red) and 490 nm (blue).

considered. For several reasons, generalization testing in extinction should be more sensitive to context effects than should the tests used in the previous experiments. In those tests, control by the context had to be strong enough to overcome opposite control by the reinforcement contingency still in effect (and in one case, possibly by the odor as well). Neverthe-

less, it would be useful to affirm that the generalization test procedure demonstrates context specificity following the standard training procedure, as used in the original study (Thomas & Empedocles, 1991) and in Group HL (Experiment 1) of the present study. This was accomplished in Experiment 5.

Subjects and Apparatus

The subjects were 8 experimentally naive pigeons maintained as in Experiment 1. The apparatus was the same as that in Experiment 4.

Procedure

The training procedure was the same as that used with Group HL in Experiment 1. The test procedure was the same as that used in Experiment 4.

RESULTS AND DISCUSSION

The individual and the group mean wavelength generalization gradients are presented in Figure 2. The results are very different from those seen in Experiment 4. Figure 2 reveals that, as expected, all 8 subjects responded much more to blue than to red in the chamber in which both original and reversal training had been carried out. In six of the eight cases, this "preference" was clearly reversed when the testing was done in the chamber used exclusively in original (red S+/blue S-) training. In that chamber, the birds responded substantially to both blue and red but more to red (except for Birds 7 and 8). Clearly, then, the generalization test method is sensitive to context-specificity effects if the training procedure is adequate to produce them.

EXPERIMENT 6

In Experiment 4 it was shown that context specificity did not result when single-stimulus training, rather than discrimination reversal training, was used in both training phases. Experiment 5 demonstrated that the generalization test procedure was adequate to demonstrate the specificity effect when the standard training conditions, involving discrimination reversal training and different odors present in the two training phases, were used. Given the finding that the use of different odors potentiated learning about apparatus cues when the discrimination reversal paradigm is

used, we asked whether context specificity could be obtained in the single-stimulus training paradigm if different odors were present in the two phases of training. Experiment 6 was designed to answer this question by providing a replication of Experiment 4, but with the odors present rather than absent.

METHOD

Subjects and Apparatus

The subjects were 16 experimentally naive pigeons maintained as in Experiment 1. The apparatus was the same as that used in Experiment 4.

Procedure

The subjects were randomly assigned to two groups ($n = 8$). The procedure used was the same as that used in Experiment 4 for one of these groups (the no-odor group). For the other group (odor group), the procedure was the same except that one of the two odors, eucalyptus oil or isoamyl acetate, was present during Phase 1 of training and the alternative odor was present during Phase 2. The Phase 2 odor was present in both boxes during generalization testing; thus, the test was identical to that used in Experiment 5. The two groups of subjects were trained and tested sequentially (i.e., the odor group completed the entire procedure and the boxes were thoroughly cleaned before the birds in the no-odor group began their training).

RESULTS AND DISCUSSION

Figure 3 presents the individual and the group average generalization gradients of subjects in the odor group calculated separately for the two chambers, the one used in both phases of training and the one used only in Phase 1. The results are very different from those of Experiment 4 (Figure 1). Note first that when tested in the chamber in which they had learned first to peck red and later to peck blue, these subjects pecked more at blue than at red. The mean number of responses was 169.8 to blue and 150.6 to red. This preference for blue, the most recently reinforced stimulus, was slight but it occurred in all 8 subjects and it was statistically significant, $t(7) = 2.72$, $p < .05$. In contrast, in Experiment 4, run without odors, the subjects showed a slight (not statistically significant) preference for red in

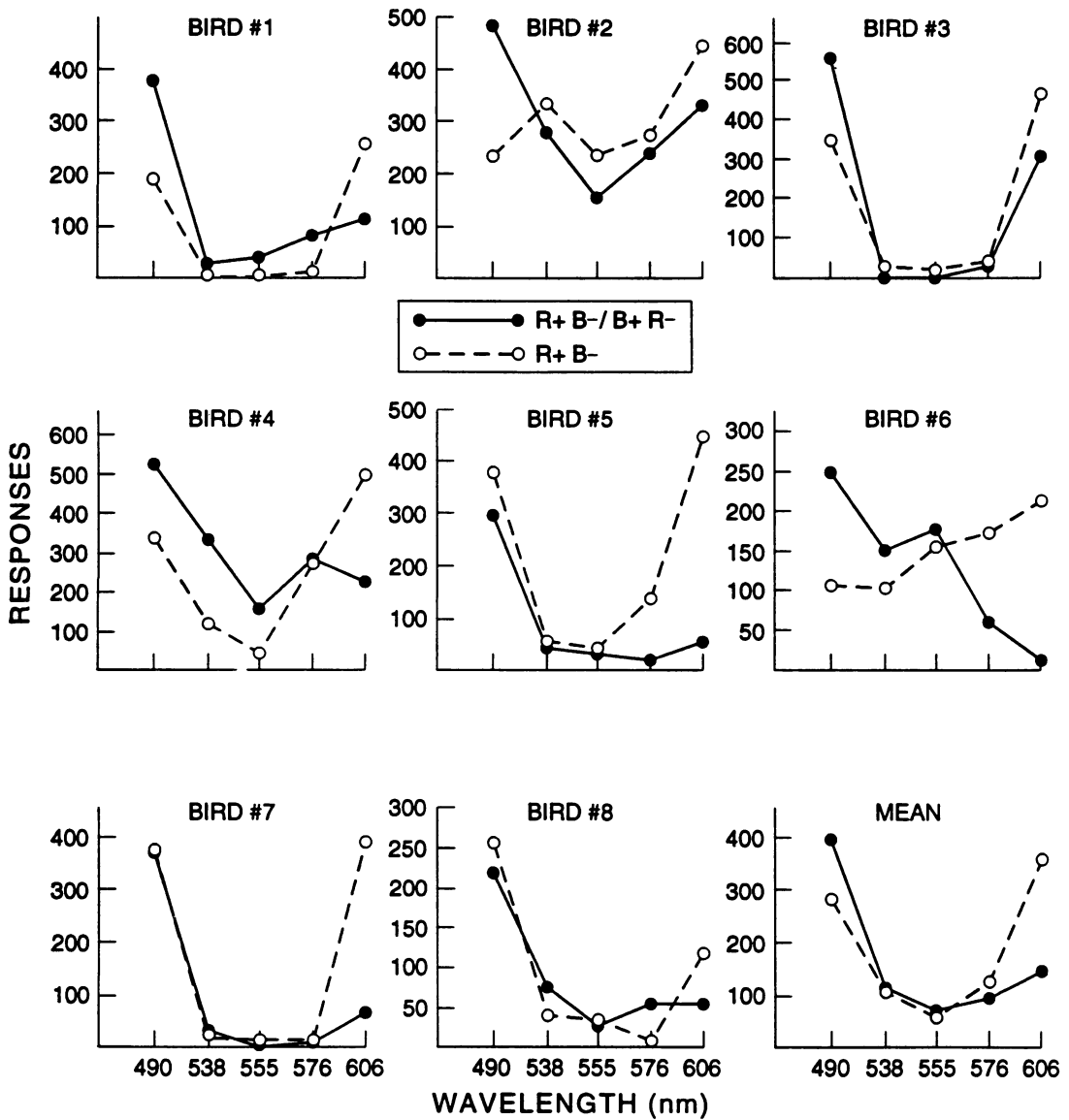


Fig. 2. Individual and group average wavelength generalization gradients obtained in two chambers, the one used in both original (Phase 1) discrimination training and subsequent (Phase 2) reversal training (R+ B- / B+ R-) and the one used only in original (Phase 1) discrimination training (R+ B-). Note that each subject was trained in two boxes during Phase 1 and in only one of those two boxes in Phase 2. The training stimuli used were 606 nm (red) and 490 nm (blue). The odor present during Phase 1 of training was that of eucalyptus oil for Birds 1, 2, 5, and 6 and that of isoamyl acetate for Birds 3, 4, 7, and 8.

both chambers. The critical evidence for context specificity comes from the birds' performance in the chamber that had been used only in Phase 1. The birds responded a mean of 128.1 times to red and 72.6 times to blue in this box, $t(7) = 4.14$, $p < .01$. Note that this preference for red occurred despite the fact that

the odor present (in both boxes) was the one that had accompanied Phase 2 of training, in which blue was the only key color present. The difference in the subjects' performance in the two chambers indicates the presence of context specificity (i.e., the effect of training the birds to peck blue in Phase 2 in one chamber was

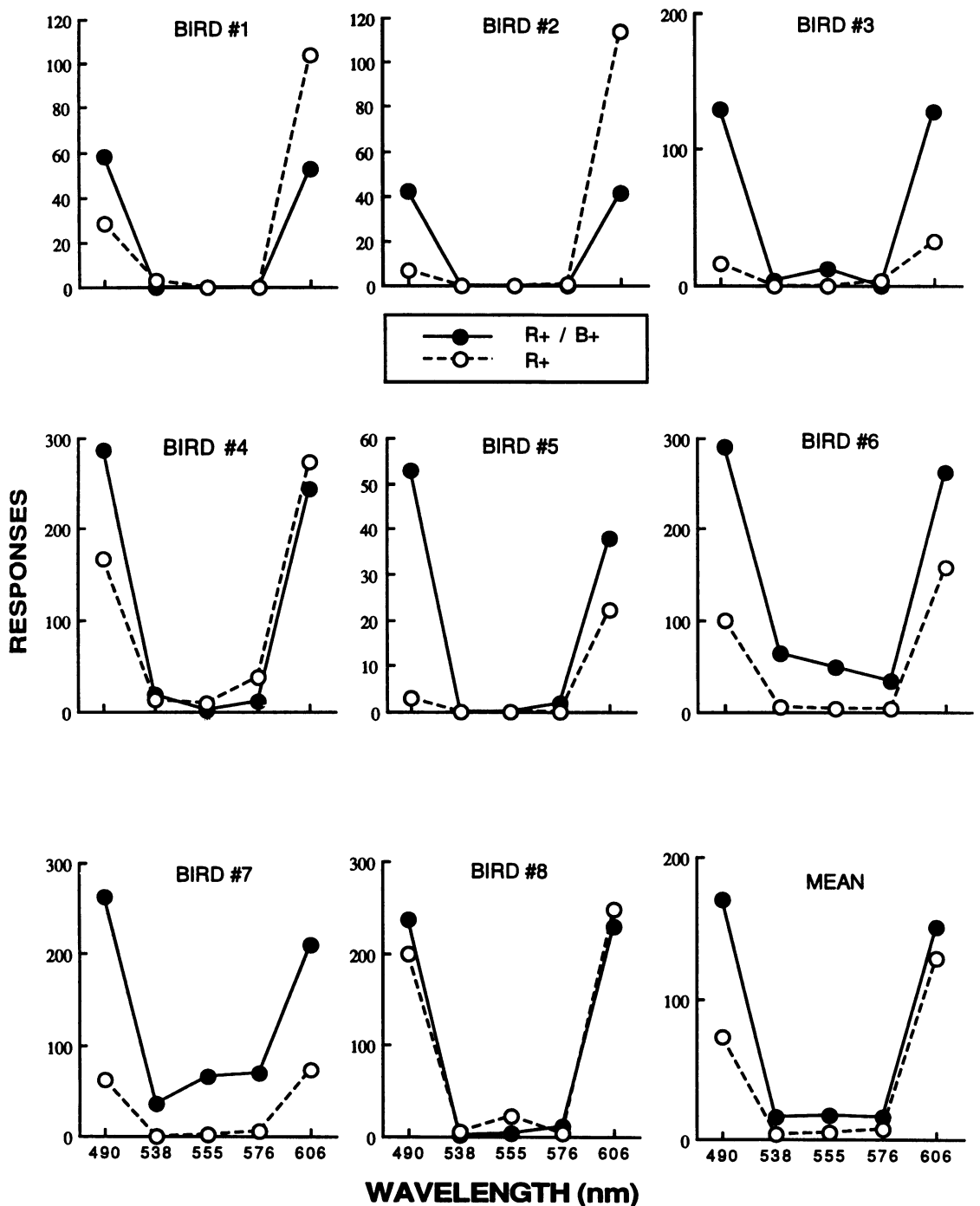


Fig. 3. Individual and group average wavelength generalization gradients of the odor group obtained in two chambers, the one used in both Phase 1 and Phase 2 of training ($R+ B+$) and the one used only in Phase 1 ($R+$). Note that each subject was trained in two boxes during Phase 1 and in only one of those two boxes in Phase 2. The training stimuli used were 606 nm (red) and 490 nm (blue). The odor present during Phase 1 of training was that of eucalyptus oil for Birds 1, 2, 5, and 6 and that of isoamyl acetate for Birds 3, 4, 7, and 8.

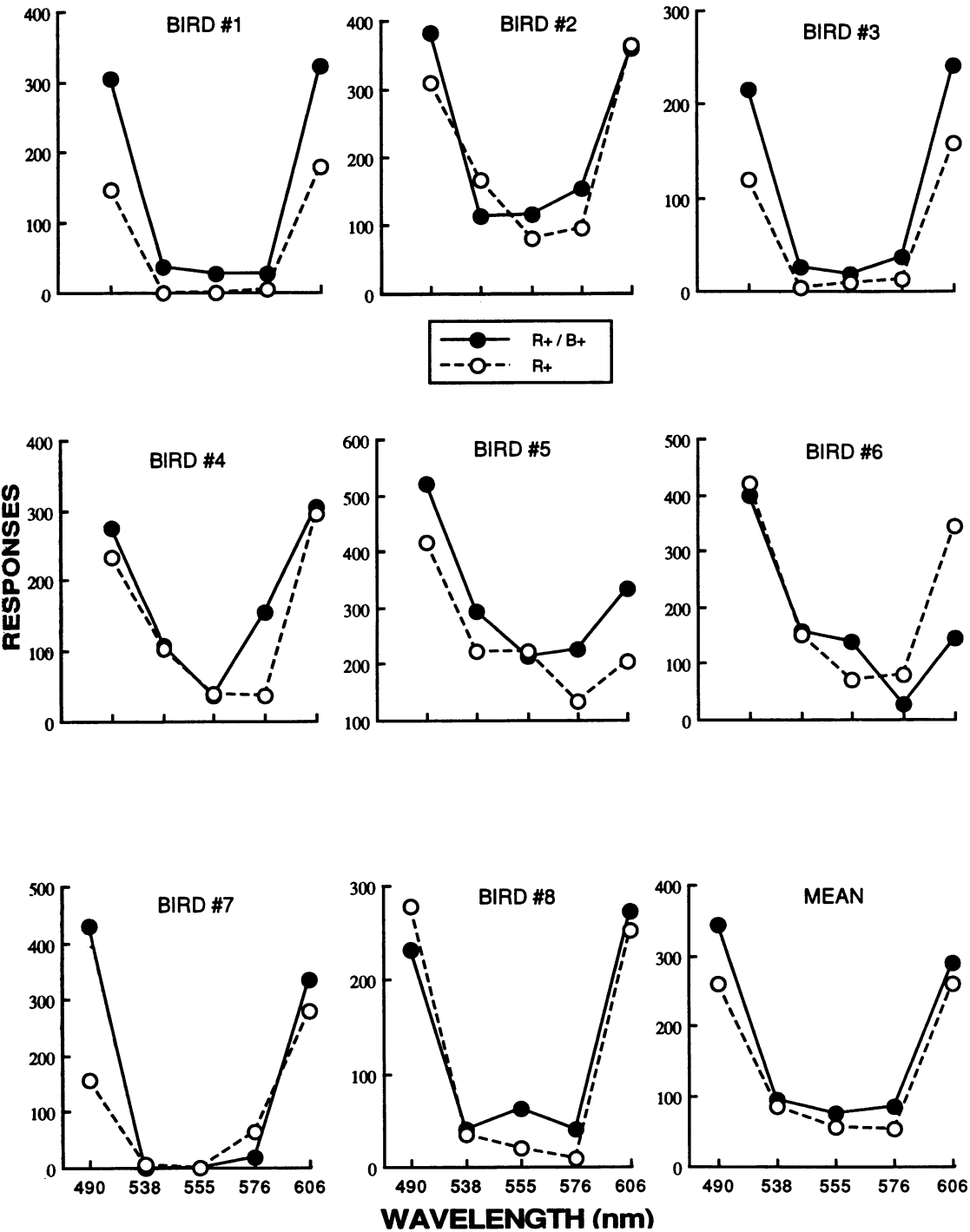


Fig. 4. Individual and group average wavelength generalization gradients of the no-odor group obtained in two chambers, the one used in both Phase 1 and Phase 2 of training (R+ B+) and the one used only in Phase 1 (R+). Note that each subject was trained in two boxes during Phase 1 and in only one of those two boxes in Phase 2. The training stimuli used were 606 nm (red) and 490 nm (blue).

largely restricted to that chamber). The transfer that did occur might be a consequence of some control over responding by the odor that was present during Phase 2 of training and that was present in both boxes during testing. This interpretation is consistent with the significant preference for blue in the red S+/blue S+ apparatus, whereas no such preference was seen in Experiment 4, for which odors were absent throughout the procedure.

Figure 4 presents the individual and the group average generalization gradients of subjects in the no-odor group calculated separately for the two chambers, the one used in both phases of training and the one used only in Phase 1. This group was treated identically to that in Experiment 4, but a direct replication seemed judicious, given that Experiments 4 and 6 were run by different experimenters more than a year apart. As may be seen in Figure 4, the essential features of the results of the earlier experiment were replicated. Summed over all test stimuli, the subjects averaged 892.2 test responses in the chamber used in both phases of training and 718.5 responses in the chamber used only in Phase 1. This difference is statistically significant, $t(7) = 2.58$, $p < .05$, and it indicates that the subjects discriminated between the different chambers. As in Experiment 4, the birds responded less in the chamber in which they had received less training and in which they had not been trained during the immediately preceding three sessions. In both chambers the subjects responded substantially and nondifferentially to red and blue, with very little responding to intermediate stimulus values. There was no significant preference for blue versus red in either chamber ($t = 1.39$ in the red S+/blue S+ box and $t < 1$ in the red S+ box). The somewhat higher mean number of responses to blue in the red S+/blue S+ chamber (344.3 vs. 288.6) is misleading. Only 4 of the 8 subjects responded more to blue than to red in this apparatus, and 2 of these 4, Birds 5 and 6, also preferred blue to the other chamber in which they had never experienced blue prior to testing. Thus no context specificity was demonstrated when the single-stimulus training paradigm was used without odors. The context specificity found in the odor group may therefore be taken to indicate that the presence of different odors in Phases 1 and 2 of training potentiated learning about the distinctive (pre-

sumably visual) features of the different chambers.

GENERAL DISCUSSION

In Experiment 1 we replicated the result reported by Thomas and Empedocles (1991), despite minor differences in number and duration of training sessions. It was also shown that when training and testing were carried out without houselights, thereby reducing the availability of visual cues that might differentiate the two boxes used in training, the magnitude of the context-specificity effect was significantly reduced. Experiment 2 demonstrated that the frequent switching between boxes in Phase 1, designed to invalidate any differences between them as potential retrieval cues, had no noticeable effect on the size of the context-specificity effect. Thomas and Goldberg (1985) had previously shown no significant effect of frequent switching between houselight and tone versus no-houselight and white-noise context, but Thomas et al. (1990) and Thomas et al. (1987) had shown that frequent switches are essential to establish conditional control by some less salient contextual stimuli. This suggests that the box cues, signaling different locations in the world, are extremely salient to pigeons, despite the fact that the actual cues utilized are not apparent to human observers.

Experiment 3 suggested that the different odors used in Phases 1 and 2 of the previous experiments potentiated learning about the box cues; the degree of context specificity obtained was significantly reduced when the odors were omitted from the procedure. Experiment 4 used single-stimulus training without odors present in both phases and obtained no evidence of context specificity. Because it employed a different (i.e., generalization) test procedure, Experiment 5 demonstrated that it was the training procedure and not the test procedure that was critical. In Experiment 6 the single-stimulus training paradigm was used, as in Experiment 4, but this time different odors again accompanied the two training phases. Under this condition, strong evidence for context specificity was found. Thus, with both single-stimulus and discrimination reversal training paradigms, we have shown that the presence of different odors during the two phases of training potentiated learning about the apparatus

cues. This finding is remarkable because the presence of the Phase 2 odor during testing has the potential to mask control over responding by the chamber that had only been used in Phase 1. It seems likely that the amount of potentiation, and hence the degree of control by (nonodor) apparatus cues, is underestimated by our test procedures.

Our findings with regard to potentiation are particularly interesting for several reasons. First, it was reasonable to expect that the use of the same odor in both boxes in Phase 1 would overshadow any subtle differences that might exist between the boxes. Second, as we have shown elsewhere (Thomas & Empedocles, 1991), the odors did not become effective conditional or retrieval cues in the single-reversal paradigm. They are capable of serving in this capacity, but only after extensive and explicit conditional discrimination (daily reversal) training.

Potentiation of learning is most frequently studied in the context of classical conditioning of aversions to stimuli paired with subsequent illness. The strongest evidence of such an effect comes from experiments with rats in which an odor that would not otherwise be an effective conditional stimulus (CS) becomes one when paired with a taste cue. This effect has been interpreted in terms of a neuroanatomical link between olfactory and gustatory systems (see Garcia, 1989). Taste can also potentiate conditioning of auditory or visual CSs, but the effect is much less strong (see Galef & Osborne, 1978, Holder, Bermudez-Rattoni, & Garcia, 1988). Note, however, that the potentiating stimulus, taste, is a powerful CS in these situations, and is capable of supporting a high level of conditioned responding.

In the present experiments the learning that was potentiated is of a higher order; it is the conditional relationship between apparatus cues and the key-color discriminations or the discriminative stimuli learned in their presence. Furthermore, those odor cues are not, by themselves, effective as conditional cues. We may speculate that the odors elicit or promote exploratory behavior, and it is through this means that visual cues that might not otherwise be noticed are attended to and learned about. Clearly, potentiation is not a unitary phenomenon, and doubtlessly different mechanisms will be found to underlie its different forms.

The use of both odor cues and a reversal paradigm contributed to the development of conditional control by box cues in these experiments. It is tempting to consider whether these two factors operate via a common mechanism. Perhaps, like novel odors, a reversal of the reinforcement contingency encourages exploratory behavior on the part of the subjects. If so, then another "surprising" change in the reinforcement contingency (e.g., a change between food items or between food and water reinforcers) might have a similar effect. By the same token, if the subjects had been familiarized with both odors prior to the start of training, the use of different odors in the two phases of training might have had no measurable effect.

What may we conclude about context specificity based on the results of these experiments? First of all, it must be acknowledged that context specificity was not "absolute" in these experiments. The magnitude of the disruption in performance, or the degree to which performance was different in the different chambers, varied with whether or not visual cues and odor cues were available to the subject. Even under the condition that produced the strongest effect, it was not the case that there was *no* transfer between the two chambers. With the discrimination reversal paradigm, for example, when returned to the chamber used only in Phase 1 of training, the subjects' performances were invariably inferior to what they had been in that chamber previously, reflecting retroactive interference from subsequent reversal training in the other chamber. Thus, context specificity refers to the degree to which transfer between chambers is less than would be expected, based upon the fact that the subjects had been explicitly trained to respond similarly in the two chambers during initial training.

When a reversal paradigm was used, the effect was a powerful one, not dependent on multiple comparisons between the two contexts in training (Experiment 2) or on the use of redundant odor cues (Experiment 3), and certainly not on the use of contexts that appear distinctively different to human observers. On the other hand, with the single-stimulus training paradigm the effect was less strong, and the potentiating effect of different odors was required to reveal it.

In closing, it is appropriate to point out that

there is another kind of context specificity that follows a different set of rules entirely. It is well established that a change in the training context can disrupt well-learned performance. Often this disruption is interpreted as a result of the absence of retrieval cues (see Balsam, 1985), although we (Thomas & Empedocles, 1991) have presented evidence suggesting that it may be entirely due to behavior elicited by novelty interfering with the target response. In such cases, context specificity may not reflect an association between learned performance and the environment in which that learning took place, and can even occur in the absence of any such association. This was shown in a series of experiments in which pigeons responded more in a familiar context than in a novel one, although *neither* of the contexts had been present during prior operant training. Indeed, it is probably inappropriate to describe the disruption in performance that results from novelty as an instance of context specificity. It is important to note, therefore, that in the present experiments, the change or disruption in performance that provided evidence of context specificity was the result of returning the birds to an apparatus in which they had previously been trained and with which they were highly familiar.

In most operant laboratories, it is common practice to train subjects in the same apparatus in every session. This seems advisable given the possibility that one or the other of these two kinds of context specificity could negatively affect performance. In applied settings, however, we would like the behavior acquired in one setting to generalize to other appropriate settings. To achieve this objective, it seems wise to train subjects in as many different settings as possible. It must be admitted, however, that context specificity of operant discriminative performance is easier to produce than to avoid.

REFERENCES

- Balsam, P. D. (1985). The functions of context in learning and performance. In P. D. Balsam & A. Tomie (Eds.), *Context and learning* (pp. 1-21). Hillsdale, NJ: Erlbaum.
- Galef, B. G., Jr., & Osborne, B. (1978). Novel taste facilitation of the association of visual cues with toxicosis in rats. *Journal of Comparative and Physiological Psychology*, **92**, 907-916.
- Garcia, J. (1989). Food for Tolman: Cognition and cathexis in concert. In T. Archer & L. G. Nilsson (Eds.), *Aversion, avoidance, and anxiety: Perspectives on aversively motivated behavior* (pp. 45-85). Hillsdale, NJ: Erlbaum.
- Holder, M. D., Bermudez-Rattoni, F., & Garcia, J. (1988). Taste-potentiated noise-illness associations. *Behavioral Neuroscience*, **102**, 363-370.
- Kamin, L. J. (1969). Predictability, surprise, attention, and conditioning. In B. A. Campbell & R. M. Church (Eds.), *Punishment and aversive behavior* (pp. 279-296). New York: Appleton-Century Crofts.
- Thomas, D. R., Cook, S. C., & Terrones, J. P. (1990). Conditional discrimination learning by pigeons: The role of simultaneous vs successive stimulus presentations. *Journal of Experimental Psychology: Animal Behavior Processes*, **16**, 390-401.
- Thomas, D. R., & Empedocles, S. (1991). Context specificity of operant discrimination performance in pigeons. *Journal of the Experimental Analysis of Behavior*, **55**, 267-274.
- Thomas, D. R., & Empedocles, S. (1992). Novelty versus retrieval cue value in the study of long-term memory in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, **18**, 22-33.
- Thomas, D. R., & Goldberg, H. (1985). Conditional discrimination learning by pigeons: The role of training paradigms. *Bulletin of the Psychonomic Society*, **23**, 256-258.
- Thomas, D. R., McKelvie, A. R., Ranney, M., & Moye, T. B. (1981). Interference in pigeons' long-term memory viewed as a retrieval problem. *Animal Learning & Behavior*, **9**, 581-586.
- Thomas, D. R., Moye, T. B., & Kimose, E. (1984). The recency effect in pigeons' long-term memory. *Animal Learning & Behavior*, **12**, 21-28.
- Thomas, D. R., Stengel, T., Sherman, L., & Woodford, M. (1987). Factors affecting conditional discrimination learning by pigeons. *Journal of the Experimental Analysis of Behavior*, **48**, 277-287.

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